1

DNA-TR-86-220-V1
SAN



# NUCLEAR WINTER SOURCE-TERM STUDIES

## Volume I—Ignition of Silo-Field Vegetation by Nuclear Weapons

Brian W. Bush
Richard D. Small
Pacific-Sierra Research Corporation
12340 Santa Monica Boulevard
Los Angeles, CA 90025-2587



1 February 1986

Technical Report

CONTRACT No. DNA 001-85-C-0161



THIS WORK WAS SPONSORED BY THE DEFENSE NUCLEAR AGENCY
UNDER RDT&E RMC CODE B3450854662 RG RR 00021 25904D.

Prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, DC 20305-1000

ADA203662

SECURITY CLASSIFICATION OF THIS PAGE

# REPORT DOCUMENTATION PAGE

| | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED | 1b. RESTRICTIVE MARKINGS |
| 2a. SECURITY CLASSIFICATION AUTHORITY<br>N/A since Unclassified | 3. DISTRIBUTION/AVAILABILITY OF REPORT |
| 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE<br>N/A since Unclassified | |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S)<br>PSR Report 1628 | 5. MONITORING ORGANIZATION REPORT NUMBER(S)<br>DNA-TR-86-220-V1 |
| 6a. NAME OF PERFORMING ORGANIZATION<br>Pacifica-Sierra Research Corporation<br>6b. OFFICE SYMBOL (If applicable) | 7a. NAME OF MONITORING ORGANIZATION<br>Director<br>Defense Nuclear Agency |
| 6c. ADDRESS (City, State, and ZIP Code)<br>12340 Santa Monica Blvd<br>Los Angeles, CA 90025-2587 | 7b. ADDRESS (City, State, and ZIP Code)<br>Washington, DC 20305-1000 |
| 8a. NAME OF FUNDING/SPONSORING ORGANIZATION<br>8b. OFFICE SYMBOL (If applicable) SPTD (Taylor) | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER<br>DNA 001-85-C-0161 |
| 8c. ADDRESS (City, State, and ZIP Code) | 10. SOURCE OF FUNDING NUMBERS<br>PROGRAM ELEMENT NO. 62715H; PROJECT NO. RG; TASK NO. RR; WORK UNIT ACCESSION NO. DH008921 |

11. TITLE (Include Security Classification)
NUCLEAR WINTER SOURCE-TERM STUDIES
Volume I—Ignition of Silo-Field Vegetation by Nuclear Weapons

12. PERSONAL AUTHOR(S)
Bush, Brian W., and Small, Richard D.

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT (Year, Month, Day) | 15. PAGE COUNT |
|---|---|---|---|
| Technical Report | FROM 850101 TO 860201 | 860201 | 34 |

16. SUPPLEMENTARY NOTATION This work was sponsored by the Defense Nuclear Agency under RDT&E RMC Code B3450854662 RG RR 00021 25904D.

17. COSATI CODES

| FIELD | GROUP | SUB-GROUP |
|---|---|---|
| 19 | 2 | |
| 20 | 13 | |

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Ignition, Desiccation, Fireball, Vegetation, Thermal Radiation, Smoke

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Smoke produced by the ignition and burning of live vegetation by nuclear explosions has been suggested as a major contributor to a possible nuclear winter. In this report, we consider the mechanics of live vegetation ignition by a finite-radius nuclear fireball. For specified plant properties, the amount of fireball radiation absorbed by a plant community is calculated as a function of depth into the stand and range from the fireball. The spectral regions of plant energy absorption and the overlap with the emitted fireball thermal spectra are discussed. A simple model for the plant response to the imposed thermal load is developed. First, the temperature is raised; the change depends on the plant structure, moisture content, and plant canopy. Subsequent energy deposition desiccates the plant and finally raises its temperature to the threshold ignition limit. Results show the development of a variable depth ignition zone. Close to the fireball, ignition of the entire plant occurs. At greater distances (several fireball radii) portions of the plant are only partially desiccated, and sustained burning is less probable. Far from the burst, the top of the

| 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT | 21. ABSTRACT SECURITY CLASSIFICATION |
|---|---|
| ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS | UNCLASSIFIED |

| 22a. NAME OF RESPONSIBLE INDIVIDUAL | 22b. TELEPHONE (Include Area Code) | 22c. OFFICE SYMBOL |
|---|---|---|
| Betty L. Fox | (202)325-7042 | DNA/STTI |

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

19. *ABSTRACT* (Continued)

stand is weakly heated, and only a small transient temperature change results. An estimate of the smoke produced by an exchange involving the U.S. missile fields shows that the burning of live vegetation only slightly increases the total nonurban smoke production.

# PREFACE

This effort continues Pacific-Sierra Research Corporation's (PSR's) study of the effects of fire generated by nuclear weapons. In this report, we develop a first theory for the ignition of live vegetation by a nuclear explosion. Our first nuclear winter study on smoke production was published in a previous PSR report [Bush and Small, 1985]. This report represents the first in a series on nuclear winter source-term studies.

The research was supported by the Defence Nuclear Agency under contract DNA001-85-C-0161. The task was monitored by Dr. Michael J. Frankel, SPTD.

## CONVERSION TABLE

Conversion factors for U.S. customary to metric units of measurement.

| To Convert From | To | Multiply by |
|---|---|---|
| acre | meter$^2$(m$^2$) | 4.046 X E +3 |
| British thermal unit foot/second (Btu/ft/s) | watt/meter (W/m) | 3.459 X E +3 |
| degree Celsius | degree Kelvin (K) | $t_K = t°_C + 273.15$ |
| degree (angle) | radian (rad) | 1.745 X E -2 |
| foot | meter (m) | 3.048 X E -1 |
| foot/minute (ft/min) | meter/second (m/s) | 5.080 X E -3 |
| mile (mi) | meter (m) | 1.609 X E +3 |
| mile/hour (mph) | meter/second (m/s) | 4.470 X E -1 |

TABLE OF CONTENTS


| Section | | Page |
|---|---|---|
| | PREFACE | iii |
| | CONVERSION TABLE | iv |
| | LIST OF ILLUSTRATIONS | vi |
| 1 | INTRODUCTION | 1 |
| 2 | RADIATION PENETRATION INTO A PLANT COMMUNITY | 3 |
| 3 | IGNITION AND DESICCATION OF LIVE VEGETATION | 13 |
| 4 | DISCUSSION | 18 |
| 5 | CONCLUSIONS | 21 |
| 6 | LIST OF REFERENCES | 22 |

XX

## SECTION 1
## INTRODUCTION

One likely consequence of a general nuclear exchange is widespread ignitions in nonurban areas. Recent estimates of smoke production [Crutzen and Birks, 1982; Turco et al., 1983; Crutzen, Galbally, and Bruhl, 1984; National Academy of Sciences, 1985; Small and Bush, 1985] are based on the burning of available dry or dead matter. Such material is only a small fraction of the biomass; ignitions in the larger fraction consisting of live vegetation were neglected. Recently it has been suggested that appreciable amounts of live vegetation will ignite in areas with a high density of targets such as ICBM fields [Pittock et al., 1986].

The moisture level of live vegetation is generally much higher than that of dead matter. Threshold ignitions in dry tinder materials such as grasses, crop residues, and forest litter have been measured in weapon tests and laboratory experiments. Moisture influences the thermal loading required for ignition, and some simple (see, for example, Bush and Small, 1985) procedures for correcting for moisture have been derived. They are valid for low moisture levels. At higher levels, (as in live vegetation), such corrections are not appropriate.

It is noteworthy that no ignitions of live vegetation resulted from any of the Nevada or Pacific nuclear weapon tests, even though some fires were expected. A coniferous tree stand (transplanted to the Nevada test site), for example, did not ignite despite sufficient energy to desiccate and ignite the canopy. Observers reported the formation of a steam cloud, which apparently shielded the canopy preventing complete desiccation and ignition [Arnold, 1952]. The test data and observations suggest that the ignition threshold is not a simple function of the thermal radiation, but must also depend on the plant architecture, spacing, and moisture distribution.

In this report, we consider the mechanics of live vegetation ignition. Briefly, the incident energy varies with slant range and depth into the stand. Plant characteristics such as leaf area, angle, and density influence the effective transmissivity and energy absorption. In some regions, sufficient energy is available to desiccate and ignite the vegetation; in others only desiccation or heating occurs.

In general, very high thermal loads are required. We thus consider in this analysis near-surface bursts such as might occur in silo fields. Sample results show that for an idealized wheat field, ignitions (but not necessarily sustained flaming) are possible only within 2 km of the fireball center.

Pages 3 through 12 deleted.

## SECTION 3

## IGNITION AND DESICCATION OF LIVE VEGETATION

To interpret the heat loadings calculated in the previous section in terms of the ignition or desiccation of the vegetation, we make several simplifying assumptions. When determining the vegetation response, we ignore the details of plant structure, and debit the available energy first for heating, then for desiccation, and finally for ignition. This calculation approximates the maximum ignition possible, since we neglect blast effects, possible explosive decomposition, the emission of a shielding layer of steam from the plants, and convective or conduction cooling of the vegetation.

We take the initial temperature of the stand as 20°C, and the moisture content (mass of water per unit mass of dry vegetation) as 100 percent. Such moisture content is typical of live vegetation [Burgan, 1979] although higher levels can occur early in the growth cycle. Initially, the thermal energy heats the plant to 100°C; subsequent energy addition vaporizes the moisture contained in the plant; and any remaining energy heats the plant above 100°C. The specific heat of water is 1 cal/g·°C and that for cellulose is 0.3 cal/g·°C. About 100 cal/g dry matter are required to bring the plant to 100°C. Approximately 550 cal/g are needed to vaporize water, and 50 cal/g to bring the plant to ignition (~ 300°C) temperature [Artsybashev, 1984]. Figure 7 delineates the heating, desiccation, and combustion zones in the stand (see Figs. 3a and 3b) for the thermal loadings displayed in Fig. 6. Combustion temperatures occur only at less than 2.5-km ground range. Partial desiccation occurs as far as 5 km, but only near the top of the vegetation. If we use the mass distribution in Fig. 3c instead of that in Fig. 3b (the total mass is the same in each case), the thermal effect on the vegetation becomes more severe near the top of the stand (Fig. 8). Although a greater volume is carbonized, the total carbonized matter is about the same since there is less mass near the top. For comparison, Fig. 9 illustrates thermal effects in a

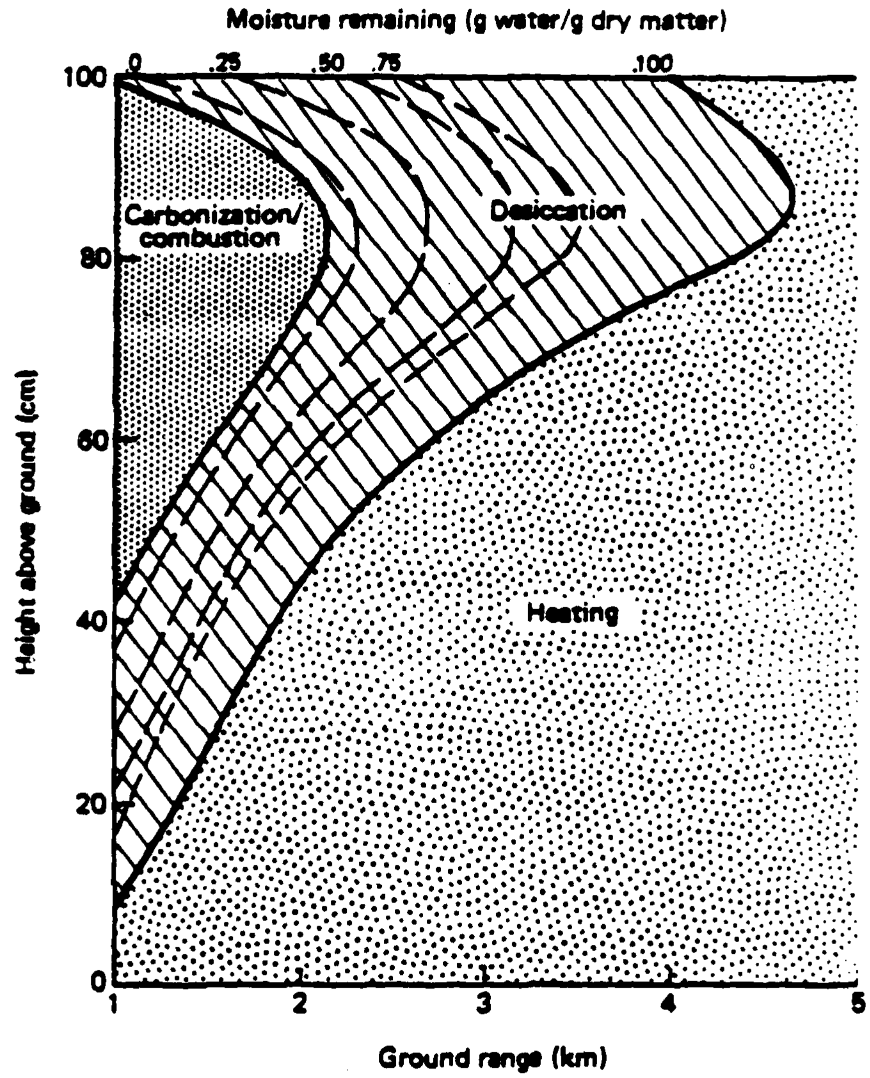


Figure 7. Thermal effects of 500 KT, 400-m burst height on idealized wheat stand (mass density is shown in Fig. 3b).

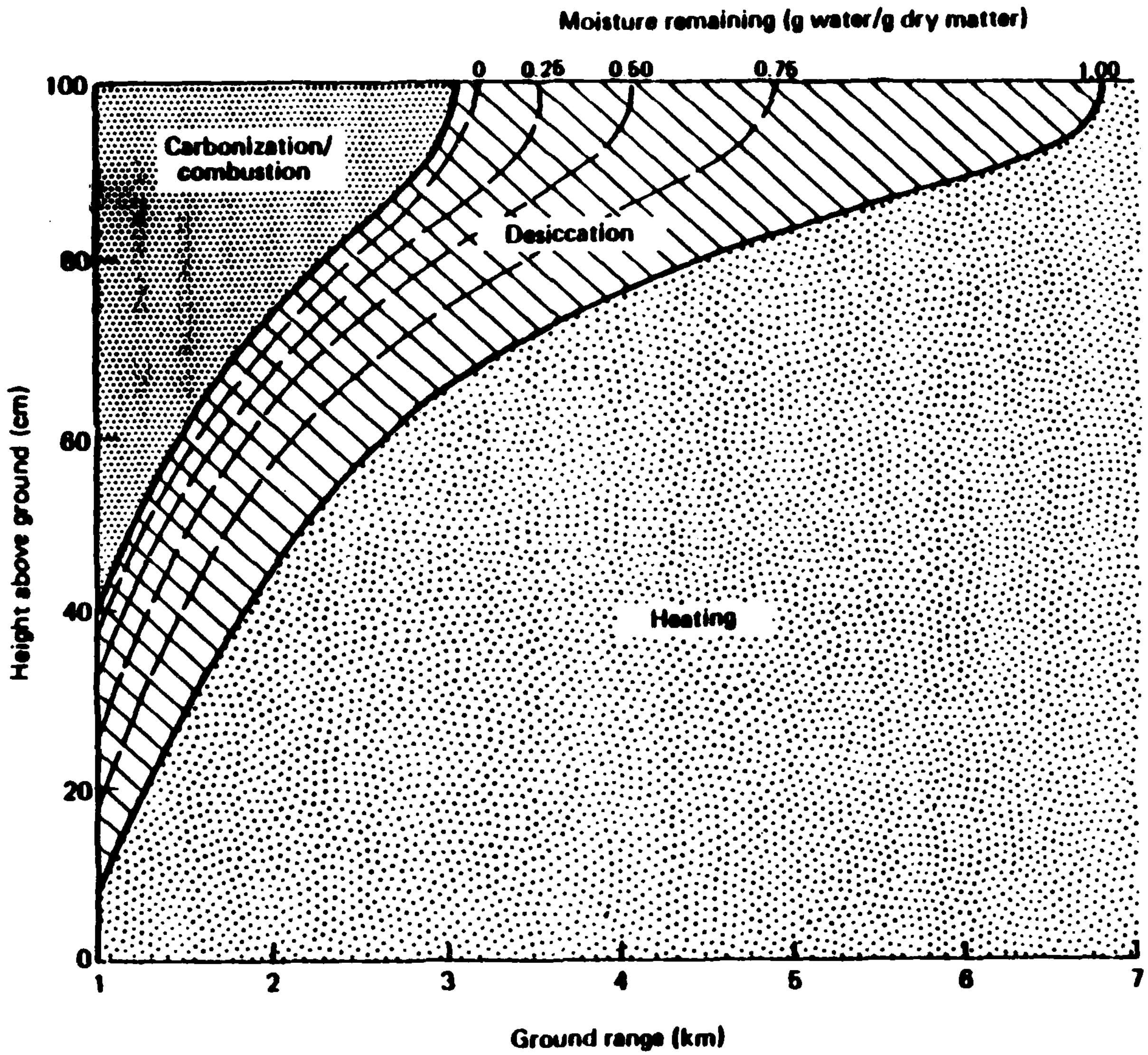


Figure 8. Thermal effects of 500 KT, 400-m burst height on idealized wheat stand (mass density is shown in Fig. 3c).

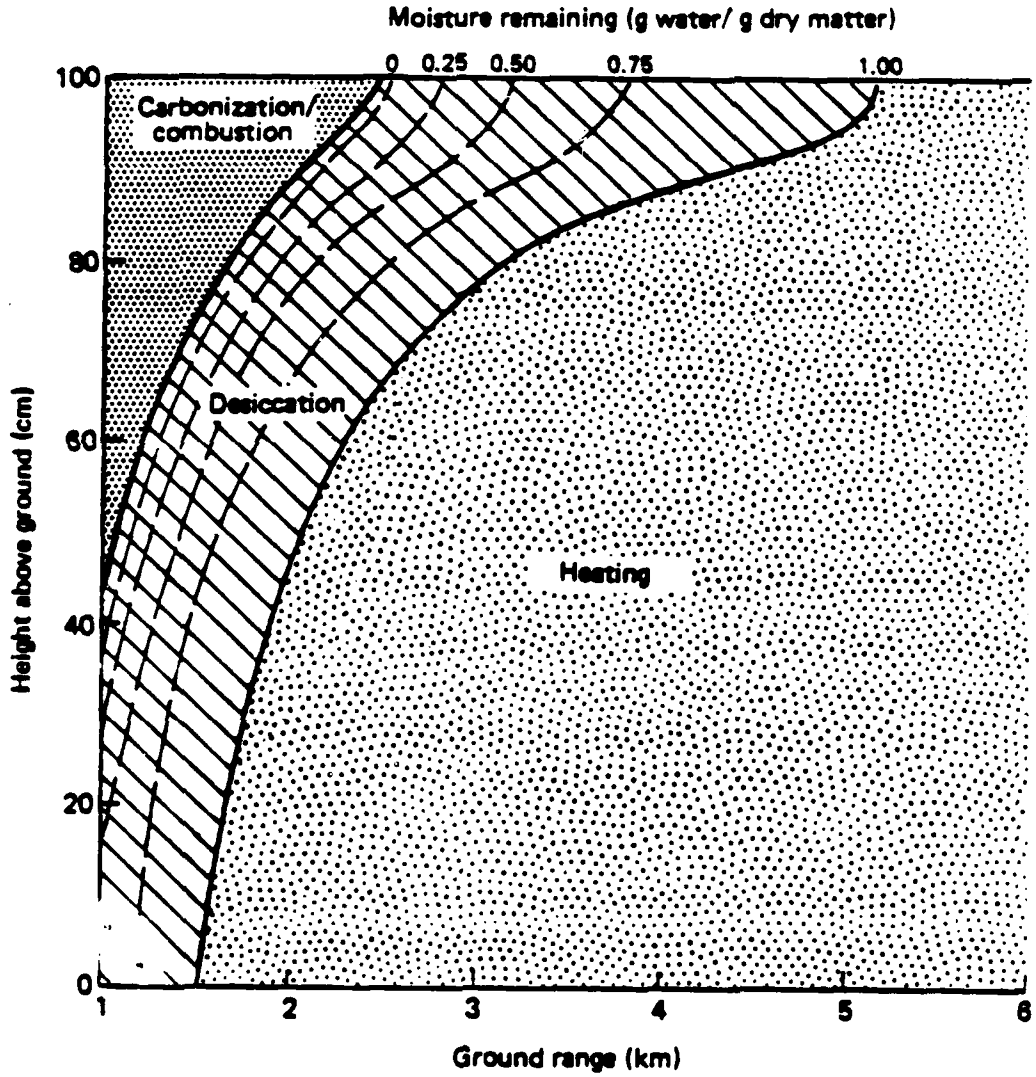


Figure 9. Thermal effects of W = 500 KT, 400-m burst height on vegetation with uniform leaf area ($3.54 \times 10^{-2}$ $cm^2/cm^3$) and mass density ($1.7 \times 10^{-3}$ $g/cm^3$).

stand with uniform leaf area and mass distribution (total leaf area and mass are the same as Figs. 7 and 8). This distribution tends to minimize the volume of carbonization, but maximize the matter carbonized. Based on these calculations, we estimate that the total amount of matter carbonized should lie in the 8.5 to 11.5 Gg range (regardless of leaf area and mass distribution) for a field with 0.17 $g/cm^2$ loading subject to a 500 KT burst at 400 m.

## SECTION 4

## DISCUSSION

We have omitted several factors that are probably important in the ignition process. It takes about 5 s to emit the first two-thirds of the thermal radiation from a 1/2-MT explosion. In that period, vegetation exposed to the radiation can change its structural and chemical composition, give off clouds of steam that scatter and absorb subsequent radiation, interact with the blast wave, and reemit thermal energy. Chemical and structural changes alter the absorptive properties of the foliage and the penetration of radiation into the stand. Clouds of steam emitted from live vegetation exposed in weapon tests have prevented radiation from penetrating a stand [Kerr et al., 1971; Arnold, 1952; Fons and Sauer, 1953]. Often, the more exposed vegetation would be charred, while even partially protected vegetation could remain unaffected by the thermal radiation; that has been observed at moderate flux levels ($Q_0$ ~ 25 to 35 cal/cm$^2$) [Arnold, 1952; Fons and Storey, 1955]. Moisture shielding the vegetation can absorb approximately 37 percent of the fireball radiation (roughly the amount of radiation in the NIR of Table 1). If charring occurs and carbon is present in the cloud, then additional (visible) radiation may be absorbed.

Blast/thermal interaction becomes important at moderate ground ranges where an appreciable fraction of the thermal radiation arrives after the shock front has passed (see Fig. 10). At those ranges the blast may uproot vegetation and rearrange material in the stand. Blast effects may either extinguish or enhance ignition, but no models currently exist to quantify its effect on cropland or grassland. Finally, the blast wave also raises dust, which can scatter thermal energy. All of the above effects are more pronounced for higher yield weapons because they emit thermal radiation over a longer period of time.

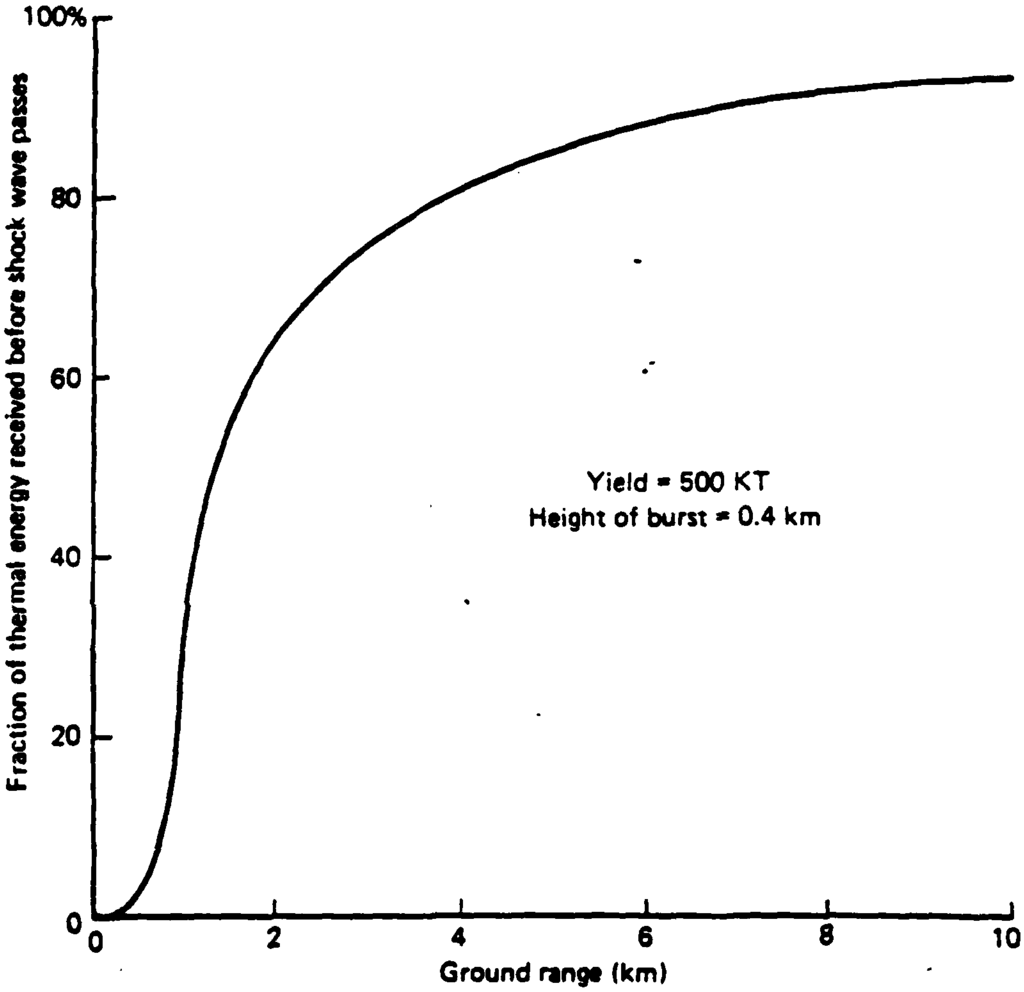


Figure 10. Thermal radiation fraction incident before shock arrival.

The detonation of more than one weapon in the vicinity of a vegetation stand introduces additional considerations. A multiple burst environment certainly will exist in ICBM silo fields. The precise situation depends on scenario and weapon reliability. Nevertheless, despite such uncertainties, we can make some plausible statements about the behavior of live vegetation in a multiple burst environment. Because targets in U.S. silo fields are spaced about 10 km apart (~ 1 silo per 100 $km^2$) [Bush and Small, 1985], even for simultaneous bursts of 500 to 1000 KT weapons on each target, desiccation and combustion will not be significantly enhanced. This is evident from the combustion and desiccation zones given in Figs. 7 through 9 (combustion occurs < 2 km, desiccation < 4 km) and from the thermal loadings in Fig. 6 ($\lesssim$ 20 cal/g beyond 5 km). Hence, silo spacing in the U.S. missile fields should not greatly influence the amount of live vegetation ignited.

Although typical U.S. silo spacing makes only a minor difference, the targeting of two weapons on the same silo could be significant. It has generally been assumed (in global effects studies) that two weapons will be targeted on each silo [National Academy of Sciences, 1985], but no explicit assumptions on the temporal separation of detonations have been made. It appears that two weapons targeted on a silo must arrive at least 10 s apart to avoid fratricidal fireball effects, and less than 1 min or more than 1 h apart to avoid fratricidal nuclear dust cloud effects [Bunn and Tsipis, 1983; McGlinchey and Seelig, 1974]. Such temporal spacings imply that the heat deposited in the vegetation stand by the first burst can dissipate by convective or radiative transfer before heat from the second burst is received. (There will, however, be some residual effects if bursts are spaced only 10 s apart.) Since the first shock wave rearranges material in the stand and possibly covers it with a dust layer, and dust in the atmosphere reduces the transmissivity of subsequent bursts, we do not expect the thermal effects to be simply additive. From Figs. 7 through 9, we see that ignition might occur in the stand top as far as about 3-km ground range due to the reheating of partially desiccated material.

## SECTION 5
## CONCLUSIONS

We have demonstrated that the canopy structure and optical properties of live vegetation must be considered in order to calculate the ignition or desiccation by a nuclear weapon. For a near-surface burst of 500 KT over an idealized wheat field, we found partial carbonization or combustion at a ground range of about 2 km and partial desiccation at about 5 km. This implies a total carbonized biomass of $10^{-2}$ Tg/burst and, therefore, roughly $2 \times 10^{-4}$ Tg/burst of smoke.

SECTION 6

LIST OF REFERENCES


Arnold, K., "Effects of Atomic Explosions on Forest Fuels," in Operation Snapper, USDA Forest Service Project 8.1, Air Force Special Weapon Project, Washington, D.C., 1952.

Artsybashev, E. S., Forest Fires and Their Control, A. A. Alkemd, Rotterdam, 1984.

Bunn, M., and K. Tsipis, Ballistic Missile Guidance and Technical Uncertainties of Countersilo Attacks, Program in Science and Technology for International Security, Report No. 9, Massachusetts Institute of Technology, Cambridge, Massachusetts, August 1983.

Burgan, R. E., Estimating Live Fuel Moisture for the 1978 Fire-Danger Rating System, USDA Forest Service Research Paper INT-226, Intermountain Forest and Range Experiment Station, Ogden, Utah, 1979.

Bush, B. W., and R. D. Small, Smoke Produced by Nonurban Target-Area Fires Following a Nuclear Exchange, Report 1515, Pacific-Sierra Research Corporation, April 1985.

Crutzen, P. J., and J. W. Birks, "The Atmosphere After a Nuclear War: Twilight at Noon," Ambio, 11, Nos. 2-3, 1982, pp. 114-125.

Crutzen, P. J., I. E. Galbally, and C. Bruhl, "Atmospheric Effects from Post-Nuclear Fires," Climatic Change, 6, 1984, pp. 323-364.

Denmead, O. T., "Temperate Cereals," Vegetation and the Atmosphere, Vol. 2, L. Monteith (ed.), Academic Press, New York, 1976, pp. 1-3[illegible]

Fons, W. L., and F. M. Sauer, "Blast Damage to Coniferous Tree Stands by Atomic Explosions," in Operation Upshot-Knothole, USDA Forest Service Project 3.19, Air Force Special Weapon Project, Washington, D.C., 1953.

Fons, W. L., and T. G. Storey, "Blast Effects on Tree Stand," Operation Castle, USDA Forest Service Project 3.3., Air Force Special Weapon Project, Washington, D.C. 1955.

Glasstone, S., and P. J. Dolan, The Effects of Nuclear Weapons, U.S. Departments of Defense and Energy, 3rd ed., 1977.

Kerr, J. W., et al., Nuclear Weapon Effects in a Forest Environment--Thermal and Fire, N2:TR2-70, Presented at N2 Panel Meeting, DoD Nuclear Information and Analysis Center, November 1969, Defense Nuclear Agency, Washington, D.C., July 1971.

McGlinchey, J. J., and J. W. Seelig, "Why ICBMs Can Survive Nuclear Attack," Air Force Magazine, September 1974, pp. 82-85.

National Academy of Sciences, The Effects on the Atmosphere of a Major Nuclear Exchange, National Academy Press, Washington, D.C., 1985.

Pittock, A. B., et al., "Physical and Atmospheric Effects," Vol. I, SCOPE 28 Environmental Consequences of Nuclear War, John Wiley and Sons, New York City, 1986.

Ripley, E. A., and R. E. Redmann, "Grassland," Vegetation and the Atmosphere, Vol. 2, J. L. Monteith (ed.), Academic Press, New York, 1976, pp. 349-398.

Ross, J., "Transfer in Plant Communities," Vegetation and the Atmosphere, Vol. 1, J. L. Monteith (ed.), Academic Press, New York, 1975, pp. 13-55.

Small, R. D., and B. W. Bush, "Smoke Production from Multiple Nuclear Explosions in Nonurban Areas," Science, 229, 1985, pp. 465-469.

Turco, R. P., et al., "Nuclear Winter: Global Consequences of Multiple Nuclear Explosions," Science, 222, 1983, pp. 1283-1292.